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Sedimentology of Triassic Rocks in the Lower Connecticut Valley

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Trip C-1

SEDIMENTOLOGY OF TRIASSIC ROCKS IN THE LOWER CONNECTICUT VALLEY

by

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INTRODUCTION

Triassic sedimentary rocks occur in a series of fault trough basins in eastern North America from Nova Scotia in the north to North Carolina in the south. One of the better studied Triassic sedimentary successions occurs in the lower Connecticut Valley

Previous sedimentological work by Krynine (1950), Lehmann (1959) and Sanders (1968) has yielded a stratigraphic framework (fig. 1; table 1), petrographic history and a broad understanding about depositional environments. Krynine's work emphasized the mineralogy and petrology of the sedimentary rocks and the climatic significance of the red color of the sediments. Lehmann (1959) revised the stratigraphy, whereas Sanders (1968) developed a lacustrine model of deposition for the fine-grained sedimentary rocks in the middle part of the stratigraphic succession.

STRATIGRAPHY

Triassic rocks in the Connecticut Valley consist of a series of interbedded red clastic sedimentary rocks and basaltic lava flows. These are intruded in several localities by dolerite dikes (fig. 1).

In the past stratigraphic subdivision in these rocks has used the basaltic lava flows as marker beds (table 1). Sedimentary formations are classified according to their stratigraphic position in relation to the three major lava flows as well as by certain physical and mineralogical characteristics (Krynine, 1950). The sedimentary rocks consist of interbedded and intertonguing fanglomerates, conglomerates, sandstones, mudstones, siltstones and claystones, which are organized into a series of environmentally controlled lithofacies.

SEDIMENTARY FACIES

Four environmentally controlled sedimentary facies occur in the Triassic sedimentary rocks of the lower Connecticut Valley. These facies are the proximal alluvial fan facies, the distal alluvial fan facies, the floodplain facies and the mixed facies. The mixed facies represents alternating lacustrine and fluvial mudflat deposition.

PROXIMAL ALLUVIAL FAN FACIES

The proximal alluvial fan facies is characterized by poorly sorted boulder and cobble conglomerates, with a matrix of granule-sized conglomerate and coarse-grained, arkosic sandstone. It occurs in all the stratigraphic units along the Eastern Border Fault (Stops 8, 9), and in the basal portion of the New Haven Arkose (Stop 1).

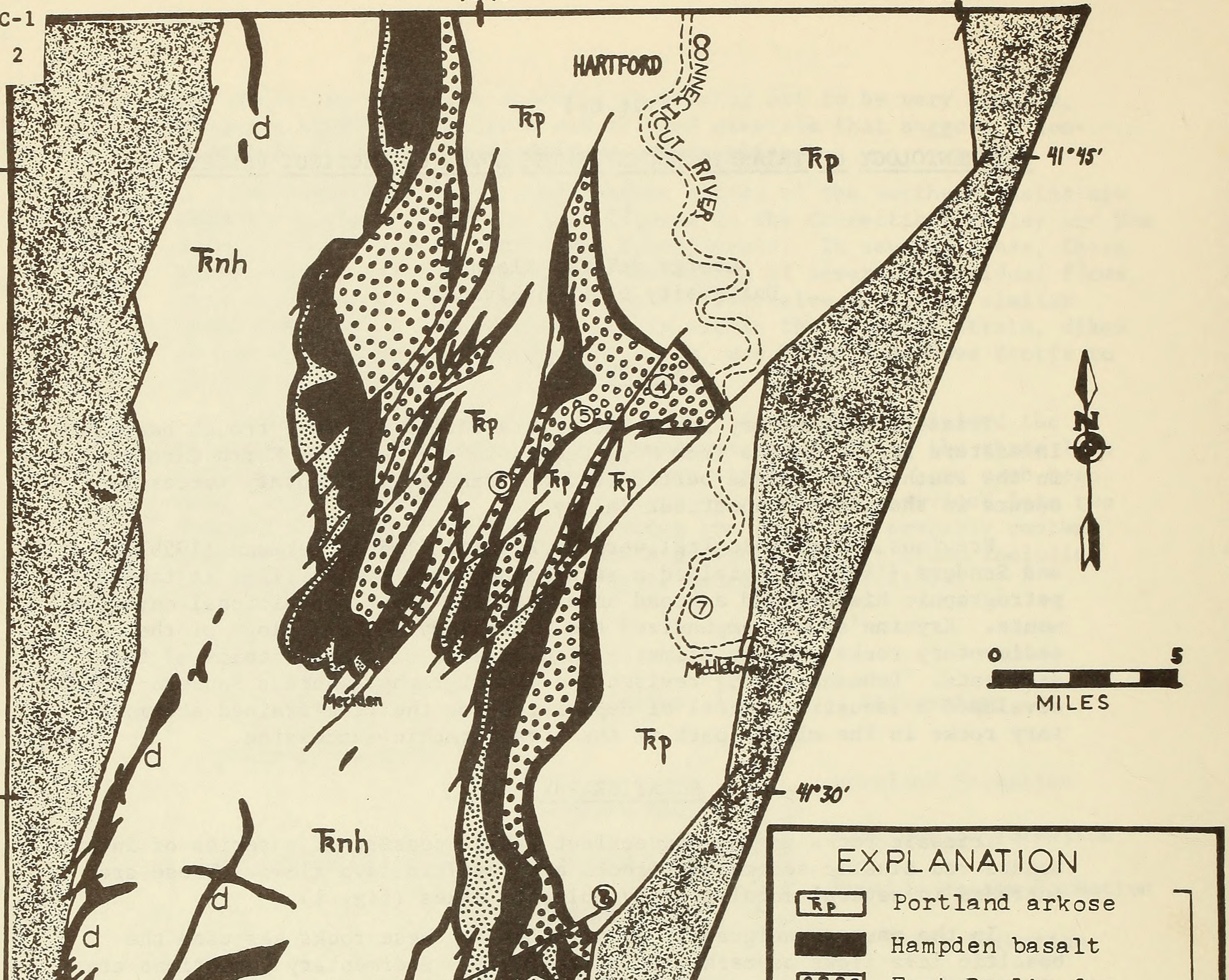

Fig. 1. Map showing Triassic geology of lower Connecticut Valley and location of stops for Trip C-1. (map after Rodgers and others, 1956).

Table 1. Triassic stratigraphy of Connecticut (after Krynine, 1950; Lehmann, 1959; Sanders, 1968).

Formation	Lithologies	Thickness	Environments
Portland Arkose	Fanglomerate, arkosic sandstone, mudstone	>450 meters	Alluvial fan, floodplain
MERIDEN GROUP			
Hampden Basalt	Basaltic lava	100 meters	
East Berlin Formation	Siltstone, mudstone, sandstone, claystone	183-485 meters	Lake and alluvial mudflat intertonguing into alluvial fan
Holyoke Basalt	Basaltic lava	200 meters	
Shuttle Meadow Formation	Siltstone, mudstone, sandstone, claystone	95-275 meters	Lake, alluvial mudflats, alluvial fans
Talcott Formation	Basaltic lava and interbedded sandstone, mudstone	150 meters	Lake, alluvial fan
New Haven Arkose	Fanglomerate, arkosic sandstone, mudstone	3,350 meters	Alluvial fans, floodplains

Evidence for an alluvial fan origin comes from previous comparisons by Krynine (1950) to modern alluvial fans and comparison to more recent studies by Blissenbach (1954) and Hooke (1967). The major evidence is the poor sorting and broad size range of the component particles, the crude stratification of the conglomerates, and the planar bedding of the sandstones. The crude sorting and bedding indicate rapid sediment dumping and burial because of the decrease in stream velocity reflecting a reduction in the depositional slope from the fault scarp to basin floor environment. Associated sandstone lenses with planar bedding indicate that, most likely, the streams building the fans flowed as sheet floods operating under the hydraulic conditions of the upper flow regime (cf. Simons and others, 1965). Patchy conglomerates and poor sorting of conglomerates may be the result of sieve deposition (Hooke, 1967), where the porous nature of the deposits resulted in the disappearance of streams from the fan surfaces into the porous interior of the fan. The cobble-, pebble-, and boulder-sized materials were left as a sieve-lag deposit. These deposits must have been formed by streams with a high sediment concentration. The presence of imbricated fanglomerates does suggest that there were episodes of deposition involving lower concentrations of sediment which permitted greater sediment reworking.

DISTAL ALLUVIAL FAN FACIES

Westward from the Eastern Border Fault the proximal alluvial fan facies is found to be interbedded with, or intertonguing with pebble conglomerates and pebbly, coarse-grained sandstones. The pebbles consist of milky quartz, feldspar, granite, pegmatite and schist. The sandstones are arkosic, coarse-grained, poorly sorted and contain angular grains. Bedding in the sandstones of the higher formations tends to be planar (Stop 9). A complete gradation from proximal alluvial fan facies to the distal alluvial fan facies can be seen at Stop 9.

The distal alluvial fan facies is also characterized by a moderately regular interbedding of coarse-grained sandstones and mudstones, such as in the New Haven Arkose (Stop 2). Here coarse-grained, arkosic, pebbly sandstones alternate regularly with silty mudstones.

FLOODPLAIN FACIES

The floodplain facies is best developed in the Portland Arkose (Stop 7) and in the New Haven Arkose (Stops 2, 3). This facies is interbedded with and intertongued with the distal alluvial fan facies.

The major rock type in the floodplain facies is coarse-grained, massive-bedded sandstone. The massive bedding ranges in thickness up to 5 meters, with thinner internal sets of 30 cm. These are interbedded with thin (5 cm) siltstone layers. Generally, the basal contact of the sandstone beds is extremely sharp and channelled into the siltstone beds below, whereas the upper contact is characterized by less of a textural distinction or is gradational.

On the upper surfaces of some of the sandstone beds, pebble and cobble trains were observed in the Portland Arkose (Stop 7). These are oriented westerly as shown by a general widening to the west, indicating stream flow from east to west.

The regular bedding, vertical decrease in particle size within beds, channel scour structures, pebble trains and fining-upward cycles suggest an association of features common to the floodplain environment.

MIXED FACIES

The mixed facies contrast with the others because they are dominated by fine-grained, even-bedded lithologies, particularly in the Shuttle Meadow and East Berlin formations. The mixed facies occurs in the center of the Connecticut depositional basin. Although such fine-grained lithologies are present in the Talcott Formation and the Portland Arkose (Sanders, 1968), the discussion here is confined to the East Berlin Formation inasmuch as the principal features of the mixed facies are spectacularly displayed in this unit at two localities: a series of highway exit cuts off Interstate Highway 91, south of Rocky Hill (Stop 5), and in a road cut on Connecticut Highway 72, 0.2 miles east of its intersection with the Berlin Turnpike (Conn. Highway 15) at East Berlin (Stop 6).

Although previous workers such as Krynine (1950) interpreted the mixed facies to represent swamp, floodplain and lake environments, Sanders (1968) interpreted them to be fossil lake deposits from hydrodynamic interpretations of the sedimentary structures, and comparison to other known lake deposits.

The mixed facies appears to be organized into complex cyclic sequences of sedimentary rocks, textures, sedimentary structures and color (fig. 4). A generalized cycle of 12 component members is indicated , although when viewed in detail, variations exist from this generalized scheme (see outcrop description for Stop 5). A total of three major cycles are exposed at Stop 5. A review of Lehmann's (1959) stratigraphic section at Stop 6 indicates that three major cycles are exposed there too.

The generalized cycle consists of the following 12 members (descending order; see fig. 4):

(1) Siltstone, red, with dolomitic concretions.

(2) Siltstone, red, with dolomitic concretions, pull-apart structures and sandstone dikes.

(3) Siltstones, red, with dolomitic concretions, sandstone dikes and mud cracks.

(4) Siltstone, red, massive, structureless.

(5) Sandstones, red in upper half, grading into gray in lower half, locally cross-stratified.

(6) Siltstones, gray, with dolomite concretions, pull-aparts and sandstone dikes.

(7) Siltstones, gray, with pull-aparts, and sandstone dikes.

(8) Siltstones, gray, with graded beds, basal part of graded beds is light-gray siltstone grading upward into dark gray siltstone.

(9) Siltstone, upper half is gray, lower half is black, thinly-bedded with flaser bedding (smeared).

(10) Claystone, black, asphaltic, pyritic.

(11) Siltstone, gray, similar to member (8).

(12) Siltstone, gray with dolomitic concretions, mud cracks and pull-aparts, grading downward into red siltstone with identical features.

Although more detailed studies, especially of mineralogy, are needed, it is the writer's personal prejudice at this moment that the cycles can be attributed to a combination of continued fault-trough subsidence and variation in the rate of sedimentation. Future work is needed to pinpoint what factors controlled the variations in the rate of sediment supply. Possibly, climatic controls were responsible, as suggested by Van Houten (1962, 1964).

<u>Stop 1</u> (18.38 N - 53.60 E). 0.25 miles west of Exit 59 of Wilbur Cross Parkway, just west of intersection of June St. and Hazel Terr., behind buildings of the Amity Shopping Center, Woodbridge, Conn.

Outcrop of proximal alluvial fan facies of the New Haven Arkose which unconformably overlies the Milford Chlorite Schist. The New Haven Arkose consists of interlayered and intertonguing cobble- and pebble-conglomerate and green, epidotic, arkosic sandstone of the proximal alluvial fan facies. Both the conglomerate and sandstone are poorly sorted. Bedding is extremely crude, roughly parallel to the basal unconformity.

The conglomerates are pebble and cobble in size. The cobble fraction contains angular and blade-shaped fragments of epidotic phyllite derived from the underlying Milford Chlorite Schist. Accessory cobbles of rounded, milky quartz also occur. The pebble fraction consists almost exclusively of rounded fragments of orthoclase and microcline, milky quartz, and

Fig. 2. Boulder and cobble conglomerate in epidotic, arkosic sandstone matrix, proximal alluvial fan facies, New Haven Arkose, Amity Shopping Center, Woodbridge, Connecticut (Stop 1). Cobble-sized material consists of phyllite (dark) whereas pebbles consist of milky quartz and granite. Scale on hammer is in inches.

Fig. 3. Interbedded pebbly sandstones and mudstones of distal alluvial fan facies and fining-upward sequence of floodplain facies. Hammer is located by a fining-upward sequence of floodplain facies. Remaining sandstones and mudstones are separated by a sharp contact. West Rock Tunnel, New Haven, Connecticut (Stop 2).

granite pegmatite. The pebbles show better rounding than the cobbles; they are disc-shaped and spheroidal (fig. 2).

Sandstone lenses and beds intertongue laterally with the conglomerates. The sandstones are green, medium- to coarse-grained, arkosic and epidotic. The sand grains are angular. Sorting is poor. Petrographic study shows that the sandstones contain quartz (21 percent), polycrystalline quartz (20 percent), recognizable rock fragments (3 percent), orthoclase (16 percent), microcline (4 percent), plagioclase (2 percent) and opaque minerals, epidote and heavy minerals (2 percent). The sandstone is cemented by calcite. About six percent calcite selectively replaces microcline and orthoclase (Badal, 1968).

Interpretation. The basal New Haven Arkose was deposited by fluvial processes and represents the proximal alluvial fan facies. The mixed sorting of the rocks, the sand-grain angularity, the poor stratification, and the mixed population of the conglomerates support this interpretation.

The separation of the conglomerate fraction into two distinct size-composition associations (phyllitic cobbles and quartzo-feldspathic pebbles) suggest two sources for the basal New Haven Arkose. The cobble fraction was probably derived locally from the Milford Chlorite Schist and transported only a short distance, whereas the pebble fraction and the sand fraction were probably derived from a more distant source. The distant source was, most likely, east of the present outcrop belt (Krynine, 1950), although derivation from western pegmatite and granite terrains should not be ruled out entirely.

Stop 2 (18.61 N - 53.88 E) Near Exit 59 of the Wilbur Cross Parkway, 50 yards northwest of south portal of West Rock tunnel, New Haven. Outcrop of the distal alluvial facies and floodplain facies, New Haven Arkose, 50 feet below West Rock Sill.

Outcrop description. The New Haven Arkose is exposed on a rock face 60 ft high by about 140 ft long. Both the distal alluvial fan facies and the floodplain facies are exposed here. The New Haven Arkose consists of seven alternating layers of coarse, purplish pink sandstone and dark red mudstone and siltstone. The sandstone is coarse-grained, pebbly and arkosic. The sand grains are angular to subangular. Sorting is extremely poor. In two sandstone beds, there are fining-upward sequences of the floodplain facies (fig. 3). In the distal alluvial fan facies, the basal and upper contact of each sandstone bed is sharp. The sandstone layers thicken and thin irregularly across the outcrop face, pinching out into siltstone in two cases (fig. 3).

Petrographic analysis of the sandstones shows that they contain quartz (30 percent), polycrystalline quartz (2 percent), orthoclase (15 percent) and plagioclase (21 percent) as major grain components. The sandstone is bound by clay matrix (20 percent) and is cemented by calcite and hematite.

The bedding of the sandstone is defined by sharp basal and upper contacts in the distal alluvial fan facies. Gradational contacts occur only in two beds which have been assigned to the floodplain facies. Although the bedding appears even and laterally-persistent at a distance, closer examination shows that the upper and lower surfaces undulate broadly, and two of the sandstone beds split similar to coal seams. Mudstone occurs between the split beds, which are of the distal alluvial fan facies.

Two of the beds appear to be graded, even though all particle sizes occur from bottom to top. The median particle size grades upward from coarse-grained sand at the base to fine-grained sand at the top of sandstone beds. The upper contact is gradational with overlying siltstones in both cases. However, isolated pebbles still occur in these siltstones. The sorting is uniformly poor in these fining-upward sequences of the floodplain facies.

The siltstones are dark red, poorly-sorted and micaceous. They contain mixed pebbles and coarse sand (up to 10 percent). The particle size of the siltstones and mudstones grades upward to claystone, where it is in sharp contact with the overlying sandstone. As in the sandstones, the pebbles occur as isolated grains.

Interpretation. These sediments were deposited in a fluvial environment as indicated by the poor sorting, the irregular stratification, the lensing and intertonguing of sandstone beds, and the occurrence of sandstone beds split like coal seams. Two of the sandstone-siltstone interbeds comprise a fining-upward sequence of the floodplain facies.

The remaining beds represent the distal alluvial fan facies. The poor sorting, the scattered pebbles and the sharp contacts suggest deposition by sheet flooding. The sheet flooding involved sediment loads of high concentration, thus accounting for the poor sorting, and the abrupt basal and upper contacts of the sandstone beds. The uniform occurrence of isolated pebbles suggests that the sheet floods occurred spasmodically and the high concentration of sediment load and the poor sorting may have reflected, in part, sedimentation by sieve deposition (Hooke, 1967).

Stop 3 (17.00 N - 56.34 E) Blakeslee Quarry, Russell Street, New Haven. Abandoned quarry in floodplain facies, New Haven Arkose.

Outcrop description. The New Haven Arkose (floodplain facies) is exposed around the quarry walls. The west side of the quarry is cut by a dolerite dike, three meters thick.

The New Haven Arkose consists of coarse-grained, thick-bedded sandstone and interbedded, thin-bedded siltstone. The sandstones are coarse-grained, arkosic, poorly sorted and pebbly. The sand grains are angular to subangular.

Pebbles of milky quartz, granite, schist and gneiss are scattered throughout the sandstone beds. On the east side of the quarry, the lower sandstone bed was observed to have a concentration of pebbles at the top of the bed.

Krynine (1950, p. 101) reported that the sandstones consisted of quartz (50 percent), microcline (38 percent), plagioclase (2 percent), biotite and muscovite (2 percent) and hematite matrix and calcite cement (6 percent).

Bedding in the New Haven Arkose is expressed by textural changes. The sandstone beds occur in sets ranging from two to 12 meters thick, averaging 4.5 meters. Interbedded siltstones average 35 cm in thickness. Local clay laminae emphasize planar bedding of the massive sandstones.

Local scour-and-fill phenomena occur at the basal contact of most of the sandstones. The relief on the resulting downward channelling ranges from five to 10 cm. The channel axes are oriented west to northwest.

The siltstones are dark red brown, thinly laminated, and clayey. They occur in beds averaging 35 cm in thickness.

Contacts between sandstones and siltstones are sharp, except in one case where sandstone beds were found to grade vertically into a siltstone bed similar to the fining-upward sequences described by Allen (1965).

Interpretation. Krynine (1950) interpreted the New Haven Arkose as of fluvial origin. Evidence for his interpretation included poor sorting, fining-upward sequences, channelling, scour-and-fill structures and concentration of pebbles at the top of sandstone beds.

The one fining-upward sequence confirms a floodplain origin for the beds. However, the concentration of pebbles at the top of the basal bed in the quarry suggests that part of the unit was deposited in a braided system at the distal portion of an alluvial fan. The concentration of pebbles was produced by dispersive stresses (Bagnold, 1956) during high concentration stream flow. Braided stream deposits are characterized by surface concentrations of gravel (Leopold and others, 1964) and by irregular sorting of associated sands. The planar bedding of most of the New Haven Arkose also suggests deposition during the plane-bed phase of the upper flow regime, a condition common to the distal portion of the alluvial fan environment.

The source of the sandstones was east of the present outcrop belt (Krynine, 1950) and is confirmed by the orientation of the channel axes (west and northwest) observed in the quarry. The streams depositing this part of the New Haven Arkose were flowing west to northwest.

Stop 4 (29.83 N - 62.52 E) Dinosaur State Park, on West St. 0.3 miles east of Exit 23 off Interstate Highway 91, Rocky Hill.

Outcrop description. For details about this outcrop, see outcrop description for Trip C-3, Geology of Dinosaur Park, Rocky Hill, Conn.

Stop 5 (28.85 N - 61.45 E to 28.94 N - 61.60 E) 1.8 miles south of Exit 23 and 1.8 miles north of Exit 21 on Interstate Highway 91. Mixed facies of East Berlin Formation in roadcuts in exits off west side of Interstate Highway 91 (proposed Exit 22). Until connecting road is finished, parking is permitted within exit along south-bound lane.

Outcrop description. The East Berlin Formation is exposed in a series of four road cuts and consists of three cyclic units of alternating red and gray siltstone, mudstone, claystone and sandstone (figs. 4, 5) overlain by the Hampden Basalt.

The East Berlin Formation is exposed in a series of four exitways. The contact of the Hampden Basalt and the East Berlin Formation is exposed in all the exitways. The exitways also give an unparalleled three-dimensional exposure of all the units comprising the East Berlin Formation.

Below the basalt is the first (or upper) cycle of the East Berlin Formation. It contains the generalized members shown in fig. 4 except that between members 2 and 3 there is a massive, brown sandstone layer. When this layer is traced from the northernmost exit to the southernmost

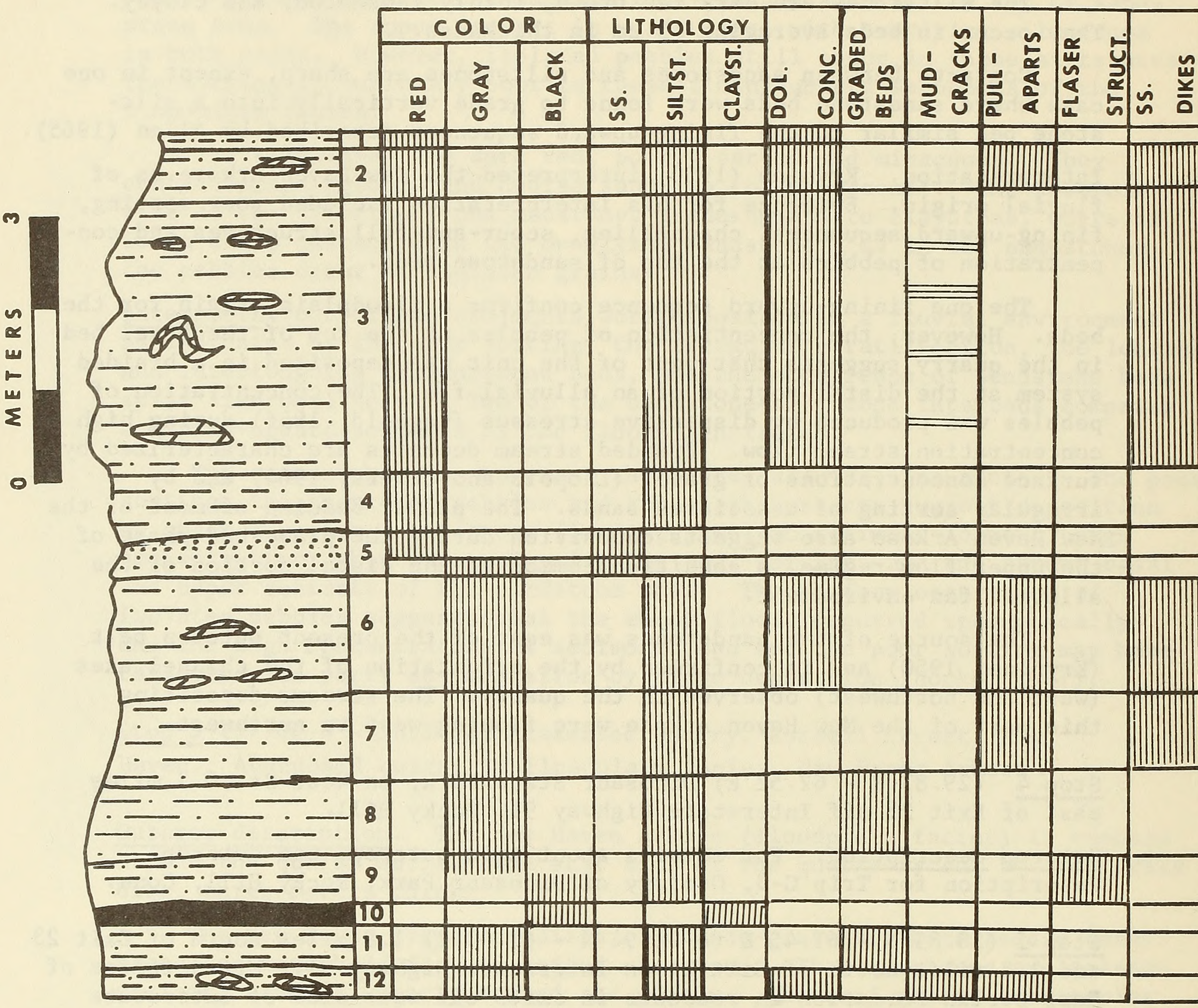

Fig. 4. Generalized cycle in East Berlin Formation, mixed facies. Members shown are (1) siltstone, red, with dolomitic concretions, (2) siltstone, red, with dolomitic concretions, pull-aparts and sandstone dikes, (3) siltstone, red, with dolomitic concretions, sandstone dikes and mud cracks, (4) siltstone, red, structureless, (5) sandstone, red in upper half, grading into gray lower half, locally cross-stratified, (6) siltstone, gray, with dolomite concretions, pull-aparts and sandstone dikes, (7) siltstone, gray, with pull-aparts, and sandstone dikes, (8) siltstone, gray, with graded beds, in which light gray siltstones grade upward into dark gray siltstone, (9) siltstone, upper half gray, lower half black, thinly bedded with flaser structure, (10) claystone, black, asphaltic, pyritic, (11) siltstone, gray, similar to Member 8, (12) siltstone, gray with dolomitic concretions, mud cracks and pull-aparts, grading downward into red siltstone with identical features.

Fig. 5. Cyclic arrangement of red and gray mudstone, siltstone, sandstone and claystone, mixed facies, East Berlin Formation, highway exits off Interstate Highway 91, near Rocky Hill, Connecticut (Stop 5). Middle cycle is shown. "a" marks asphaltic, black claystone, showing symmetrical nature of the cycle.

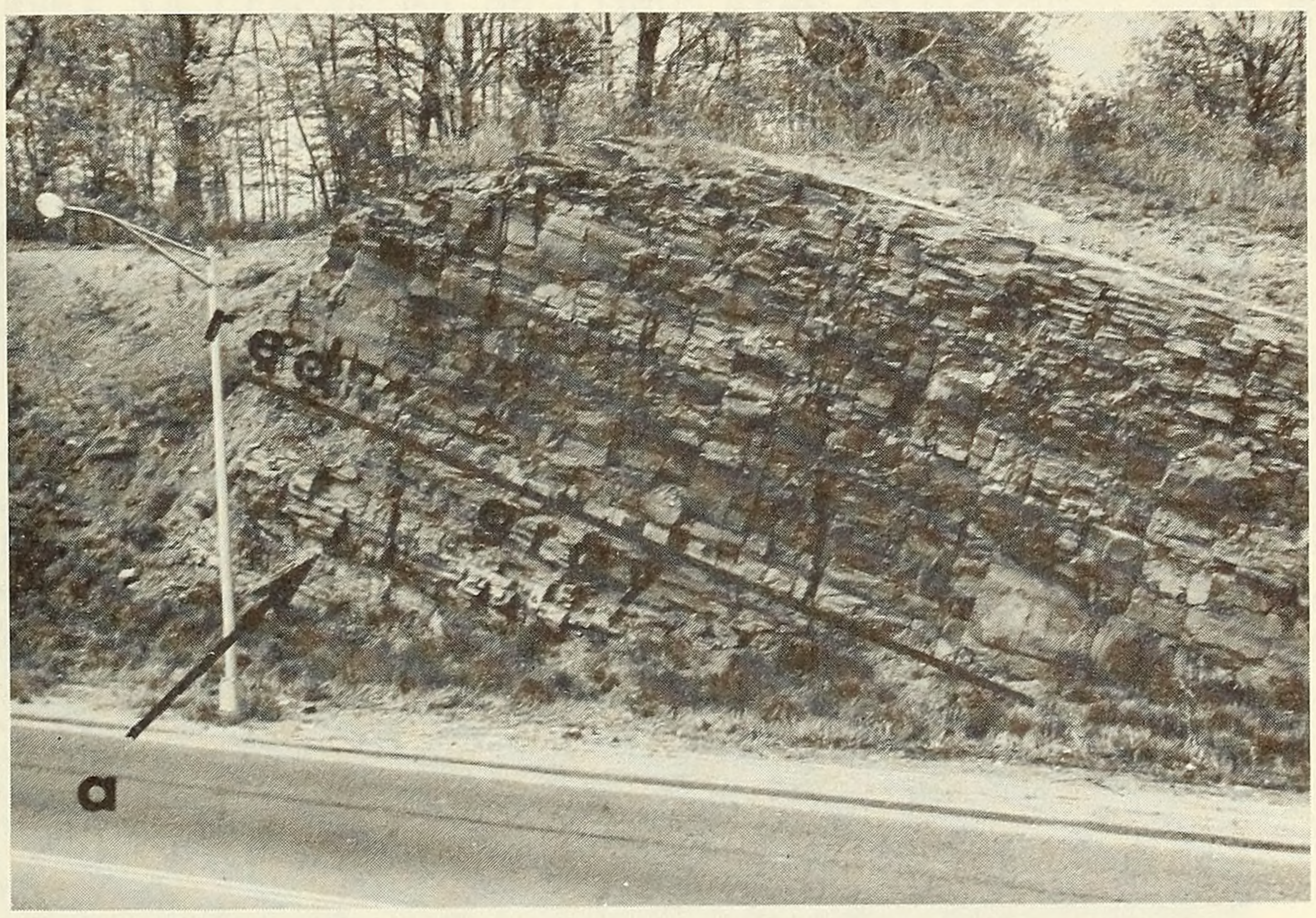

Fig. 6. Mudstones, siltstones and shales of mixed facies, East Berlin Formation, East Berlin, Connecticut (Stop 6), showing middle cyclic unit. "a" refers to asphaltic, black claystone (Member 10; fig. 10). Cycle consists of ordered arrangement of lithologies shown in fig. 10, and alternation of red and gray color.

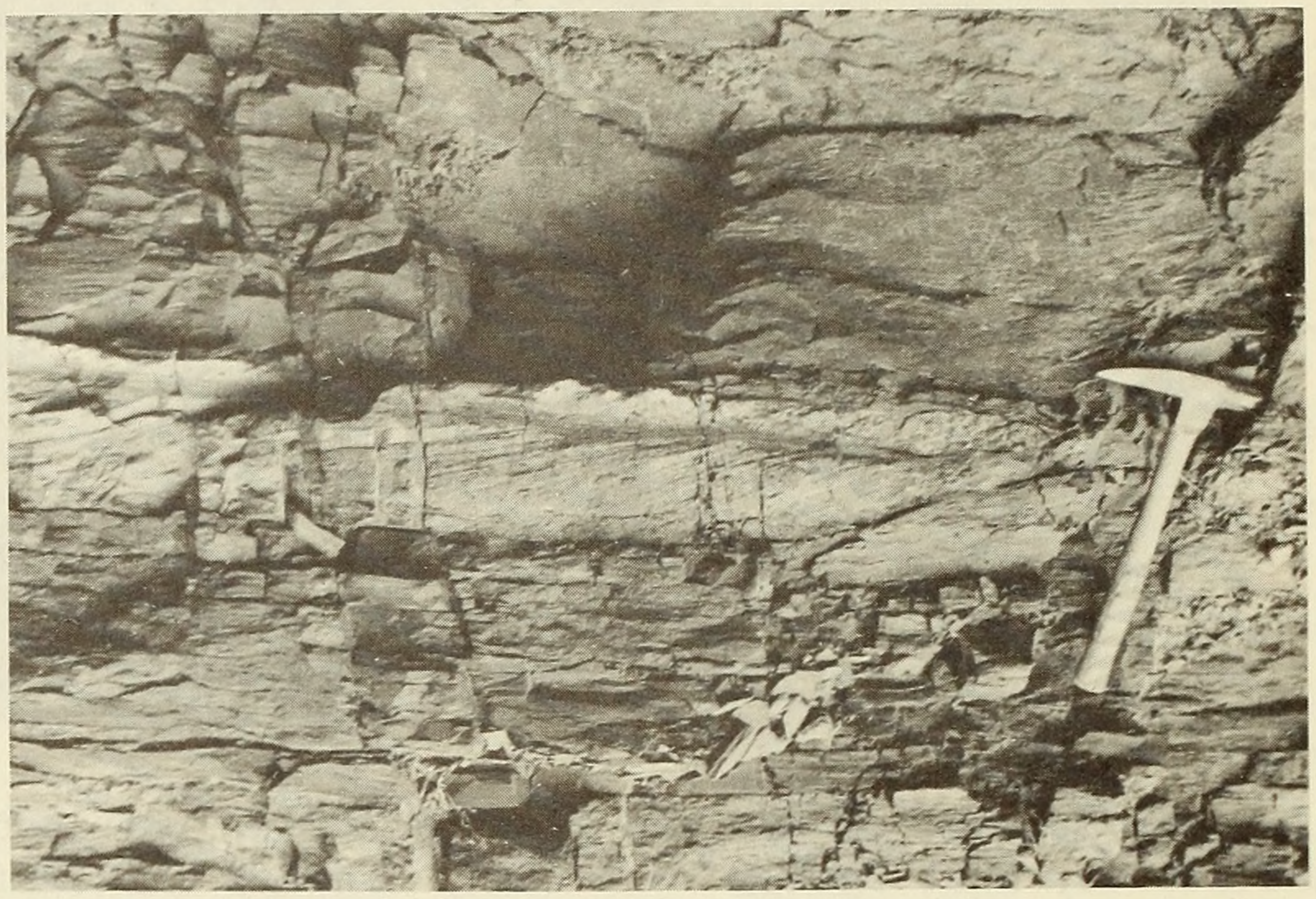

Fig. 7. Lens of cross-stratified sandstone in channel sandstones, mixed facies, East Berlin Formation, East Berlin, Connecticut (Stop 6). Channel bottom is covered by massive sandstone, which is overlain in turn by muddy topsets of overlying cross-stratified sandstone. Scale on hammer handle is in inches.

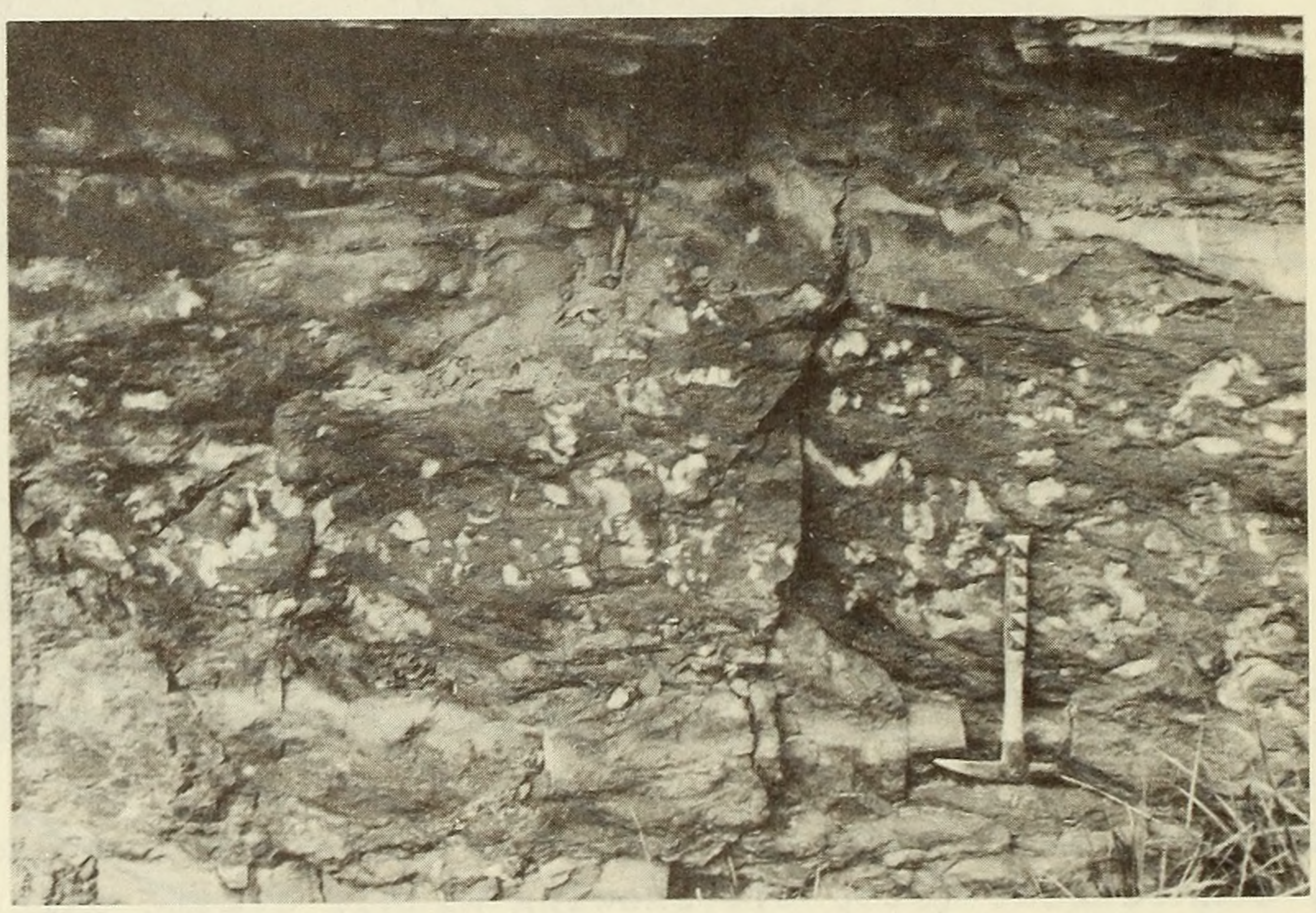

Fig. 8. Dolomitic concretions in structureless red siltstone, East Berlin Formation, East Berlin, Connecticut (Stop 6). Scale on hammer handle is in inches.

exit, one can observe sharp changes in thickness, indicating a channel geometry. The sandstone is 30 cm thick in the northernmost exit, and increases to 50 cm in thickness in the northcentral exit. In the south-central exit, sharp thickness changes occur. On the north face of this exit, the sandstone is 1 meter thick, but on the south face, the sandstone ranges from 1 meter to 3 meters in thickness. The thickness change on this south face is in the downdip (easterly) direction. In the southernmost exitway, the same sandstone layer thins to 70 cm. The thickening is always at the expense of the underlying beds. Cross-stratification in this channel is oriented to the east.

Within the red siltstones and mudstones of the red phase of the topmost cycle are a series of cross-stratified sandstone lenses. The cross-stratification is oriented east, north, northeast and west in these lenses. The inclination of the cross-stratification changes from low-angle (10 degrees) to high angle (25 degrees) within the same lense.

The siltstones are structureless. Some of the siltstones contain dolomitic concretions, some of which are contorted into "S"-shaped folds, suggesting penecontemporaneous deformation. These are often associated with beds showing pull-apart structures, syneresis cracks and sandstone dikes. Other sedimentary structures include rain prints, mud cracks, current ripple marks and rib-and-furrow structures. The topmost red phase is 16.8 meters thick (Byrnes, 1968).

The contact with the underlying gray beds is gradational, falling within a massive siltstone bed. Siltstones with dolomitic concretions, pull-apart structures, sandstone dikes, and syneresis cracks occur. The apex of the gray cycle is a black, asphaltic claystone with pyrite. This asphaltic layer is bracketed by light gray siltstones with graded bedding. The gray phase of the topmost cycle is 6.3 meters thick (Byrnes, 1968).

The second cycle (fig. 5) fits the 12-member generalized cycle (fig. 4). The top of the cycle is an undulating, gradational contact within a siltstone bed. The red phase of the second cycle totals 5.0 meters in thickness (Byrnes, 1968).

The gray phase of the second cycle (fig. 5) contains a mudstone layer at the top, a brown sandstone below and a gray siltstone with dolomite concretions below the brown sandstone. This gray siltstone grades downward into siltstone with graded bedding below which is a dark gray and black siltstone with flaser bedding. The apex of this gray cycle is another asphaltic black claystone. The gray phase of this middle cycle is 5.7 meters thick (Byrnes, 1968).

The third cycle below is in gradational contact with the second cycle. The red phase fits the generalized cycle shown in fig. 4 . It totals 9.0 meters in thickness.

The underlying gray phase (also in gradational contact with the overlying red phase) also fits the generalized cycle (fig. 4). The black asphaltic claystone is cut by thin gypsum veins, however. The lowermost gray phase totals 3.1 meters in thickness.

Below the third cycle are a series of red claystones, mudstones, siltstones and sandstones, the base of which is not exposed. On the south face of the northernmost exitway, there is exposed a sandstone layer 5 cm thick. The surface of this sandstone layer shows asymmetrical and symmetrical wave-like bedforms, whose wavelength is 25 cm, height 2.5 cm. The steep face of the asymmetrical bedform dips east, as does its internal lamination. The same asymmetrical bedform was found to grade laterally into a symmetrical wave-like bedform which contains internal laminae conformable to the surface wave-like bedform. It is suggested that the asymmetrical bedform possibly may represent a preserved antidune which grades laterally into a preserved standing wave. These bedforms are smaller in size and consist of finer-grained sediment than those reported by Hand and others (1968) in the Triassic of Massachusetts. Indirect line of evidence support for the hypothesis that these bedforms are antidunes and standing waves is that the internal stratification dips opposite to the prevailing westerly orientation of cross-laminae. Perhaps some of the easterly-oriented cross-stratification occurring in the red members of the first and middle cycle may have been so formed and would therefore be an unreliable indicator of transport direction.

Further field work is needed to check this possibility. The standing waves and antidune bedforms occur 43 meters west of the westernmost culvert, on the south face of the northernmost exitway.

Interpretation. The mixed facies probably represents an alternation of lacustrine and alluvial mudflat sedimentation. The asphaltic claystone, the graded siltstone and the siltstones with flaser bedding are interpreted to represent lacustrine deposition, whereas the gray siltstones with concretions, and the transitional gray and red sediments are interpreted to be alternating lacustrine and alluvial mudflat deposition. The higher red beds with channel sandstones are interpreted to represent alluvial mudflat deposition.

Stop 6 (28.74 N - 60.41 E to 28.83 N - 60.29 E) Road cut on Connecticut Highway 72, 0.2 to 0.6 miles east of intersection with Connecticut Highway 15. Mixed facies of East Berlin Formation, East Berlin.
N.B. WATCH THE TRAFFIC AT THIS STOP.

Outcrop description. The East Berlin Formation is overlain by the Hampden Basalt at the east end of the outcrop. The Hampden Basalt is tholeiitic and vesicular and has baked the underlying siltstones of the East Berlin Formation.

The East Berlin Formation consists of an alternating sequence of sandstone, siltstone, mudstone and claystone. These are organized into a complex of lithologic cycles (fig. 6) associated with color changes from red to gray (fig. 4). A measured section of the outcrop appears in Lehmann (1959, p. 16-21). Because of covered intervals between some of the contacts, the repetitive nature of the cycles is not as apparent as at Stop 5.

The thicknesses of the cyclic units are taken from Lehmann (1959) and converted into metric units:

Topmost cyclic unit:	Red phase	- 6.0 meters
	Gray phase	- 2.5 meters
Middle cyclic unit:	Red phase	- 5.7 meters
	Gray phase	- 6.4 meters
Basal cyclic unit:	Red phase	- 5.1 meters
	Gray phase	- 5.2 meters

The organization of the cycles fits the general cycle summarized in fig. 10.

Interbedded with the middle red phase are brown to reddish brown, fine-grained to medium-grained, orthoquartzitic sandstones. These occur as lenses which channel into the underlying beds. The sandstones are cross-stratified (fig. 7). Some mud was transported and incorporated into the cross-stratified sand.

The siltstones show a variety of sedimentary structures including contorted dolomitic concretions (fig. 8), pull-apart structures, mud cracks, raindrop imprints, current ripple marks, rib-and-furrow structures, syneresis cracks, sandstone dikes and micro-cross-laminae. Graded bedding is confined to gray siltstones which bracket asphaltic claystones. No flaser structure was observed at this outcrop.

Although the organization of the cycles at Stops 5 and 6 is generally the same, there are major thickness differences. The topmost cycle at Stop 6 is much thinner than its counterpart at Stop 5. The middle cycle is about the same thickness as its counterpart at Stop 5, whereas the basal cycle shows a thinner red phase and a thicker gray phase at Stop 6. These changes probably indicate lateral differences in the geometry of the depositional basin.

Interpretation. As at Stop 5, the mixed facies of the East Berlin Formation is believed to represent alternating lacustrine and alluvial mudflat sedimentation. The asphaltic black claystone and bracketing graded siltstones represent lacustrine deposition, whereas the upper portion of the gray phase (with concretions) and the lower part of the red phase (also with concretions) probably represent the transition zone of the two environments. The upper portion of the red phase, which contains cross-stratified sandstones, most likely represents the alluvial mudflat environment.

Stop 7 (27.16 N - 62.97 E) Entrance to Brazos Quarry, off Brownstone Ave. 0.5 miles north of intersection with Silver Street, Portland, in the floodplain facies of the Portland Arkose.

Outcrop description. The Brazos Quarry was worked for building stone during the nineteenth century. Most of the stone quarried from it was used for construction in the west side of New York City and other buildings in northeastern U.S.A. The quarry has been flooded since the First World War. A prolific number of fossil dinosaur footprints, many now housed at the Geology Department of Wesleyan University, have given the quarry its geologic fame.

The northwest part of the quarry, the only accessible part, exposes the floodplain facies of the Portland Arkose. The Portland Arkose consists mostly of massive, red-brown, coarse-grained and medium-grained sandstones interbedded with thin sets of mudstone. The sand grains are subangular to subrounded and are poorly sorted. The mudstone is dark reddish brown and thinly bedded. It occurs in thin sets averaging 5 cm in thickness.

Bedding in the sandstones is massive, occurring in sets of 3 to 4 meters thick. Within these massive sets are less well developed thinner sets ranging from 1 to 10 cm. The bed thickness was observed to decrease upward within a large massive set. The bedding is essentially planar.

Mud cracks are common on bedding planes. Dinosaur footprints were associated with mud cracks and asymmetrical ripple marks in slabs in the collections at Wesleyan University.

On the surfaces of some of the bedding planes are pebble and cobble conglomerate trains. The pebbles and cobbles consist of fragments of milky quartz, granite, pegmatite, schist, phyllite, amphibolite and gneiss. The conglomerates are openwork and are associated with a matrix of coarse-grained sandstone. The orientationsof the cobble and pebble trains are nearly east-west, with the trains widening to the west and thus indicating a flow from east to west.

Petrographic study of the sandstones shows that they consist of quartz (20 percent), microcline (2 percent), orthoclase (14 percent), plagioclase (37 percent) and recognizable metamorphic rock fragments (12 percent). The rock fragments have a diagenetically-altered rim in which biotite is altered to hematite. The sandstones are cemented by calcite (10 percent) and hematite (7 percent).

Interpretation. The Portland Arkose at this locality represents a floodplain. The planar bedding of the sandstones suggests deposition by rivers in the upper flow regime, although the vertical decrease in bed thickness of massive sets also indicates a vertical decrease in stream capacity and competency. These river systems flowed from east to west. The presence of mud cracks and fossil footprints indicates that the fluvial environment was periodically exposed but also rapidly buried. Although this outcrop represents the floodplain facies, some intertonguing elements of the distal alluvial fan facies may be present.

Stop 8 (22.82 N - 61.92 E) On Conn. Highway 77, 0.3 miles south of intersection with Conn. Highway 17. Roadside outcrop in proximal alluvial fan facies, Portland Arkose, Durham.

Outcrop description. The Portland Arkose consists of coarse conglomerate typical of the proximal alluvial fan facies. It is a typical fanglomerate. Outcrop size analysis shows that 35 percent of the fragments are cobbles, 15 percent are boulders and 25 percent are pebbles. The remainder of the rock consists of a coarse-grained, arkosic sandstone matrix.

The conglomerate fragments consist of granite, polycrystalline quartz, milky quartz, metamorphic quartzite, schist, gneiss, pegmatite, and amphibolite, all similar to rocks occurring in the Eastern Highlands. Locally, boulders and cobbles of Triassic basalt are present. The fragments are blade-shaped and poorly sorted. Orientation of fragments is mostly random.

Crude imbrication occurs at a few horizons. At the southern end of the outcrop, imbrication is oriented 120 degrees (indicating depositional flow in a direction of 300 degrees). In the center of the outcrop, the imbrication shifts to 70 degrees (flow to 250 degrees), and on the north side of the outcrop, the imbrication again is 120 degrees.

Bedding in the conglomerate is crude to nonexistent. It is indicated locally by zones of pebble, cobble and boulder conglomerate, and planar bedding in sandstone lenses. Bedding in the sandstone is in sets up to 50 cm thick, averaging 3 cm in thickness. The sandstone occurs as lenses, some of which channel into conglomeratic beds. The relief on these channels is 5 to 7 cm.

Interpretation. The Portland Arkose at this locality represents the proximal alluvial fan facies, nearly adjacent to the Eastern Border Fault. The fan sloped to the west, although the slope was irregular as indicated by shifts in pebble imbrication. The presence of crude planar-bedded sandstone suggests that the flow conditions were dominantly of the upper flow regime. The random orientation of most of the pebbles and cobbles indicates that the flow conditions were characterized by high sediment concentrations, accounting also for the lack of sorting. Possibly sieve deposition (Hooke, 1967) accounts for this high concentration.

The source of the conglomerate was east of the present outcrop belt, probably nearby.

Stop 9 (20.43 N - 61.40 E) Outcrops in proximal and distal alluvial fan facies, Portland Arkose, on Conn. Highway 77, on west side of Lake Quonnipaug, 5.2 miles south of intersection of Conn. Highway 17 and 77.

Outcrop description. North of a granite bandstand, a series of outcrops in the East Berlin Formation representsthe lateral tonguing of the proximal and distal alluvial fan facies. This facies change can be studied best by starting to examine outcrops 0.2 miles north of the bandstand in the proximal alluvial fan facies, and working back to the bandstand where the distal alluvial facies is exposed.

The predominant rock type at the northern end of the outcrop is a fanglomerate of the proximal alluvial fan facies. The fanglomerate is grayish red, poorly sorted, and contains cobbles and pebbles in a matrix of granule conglomerate (fig. 9). The fanglomerate is open-work, the cobbles and boulders being angular to subangular. Their shape is blade-like. No imbrication occurs. Bedding is indeterminate. The cobbles and boulders consist of schist, gneiss, amphibolites, milky quartz, granite, pegmatite, and Triassic basalt.

The East Berlin Formation changes southward, becoming more of a cobble conglomerate; the amount of interbedded sandstone progressively increases. The sandstone occurs as lenses, and as a conglomerate matrix. The sandstone is also grayish red and is coarse-grained, with accessory granule-size materials. Sandstone bed thickness averages 3 to 4 cm.

By the granite bandstand, cobble conglomerate and sandstone alternates (fig.10). The cobbles are slightly imbricated with the imbrication oriented 135 degrees, indicating fluvial flow in a direction of 315 degrees.

The sandstone is coarse-grained, arkosic and even bedded, the bed units being 5 mm to 1 cm. Larger order bedding averages 2.5 meters in thickness.

Interpretation. The East Berlin Formation represents an alluvial fan at this locality. The changes in lithologies observed from north to south represent a change in depositional regime from the proximal facies of an alluvial fan to the distal facies of the same alluvial fan. Deposition was by streams flowing under the hydraulic conditions of the upper flow regime, as indicated by the planar bedding. Flow concentration shifted from high (cobble fanglomerates on the north) to low (sandstones and imbricated conglomerates at the bandstand). A braided system of drainage, coupled with sheetflooding is suggested. The flow of these streams was essentially to the northwest and west.

Fig. 9. Boulder- and cobble-conglomerate, proximal alluvial fan facies, East Berlin Formation, Lake Quonnipaug, Connecticut (Stop 9). Scale on hammer handle is in inches. Matrix of conglomerate consists of granule-conglomerate and coarse-grained sandstone.

Fig. 10. Imbricated cobble-conglomerate interbedded with planar-bedded pebbly sandstone, distal alluvial fan facies, East Berlin Formation, Lake Quonnipaug, Connecticut (Stop 9). Scale on hammer handle is in inches.

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